ROCKETS *as* RESEARCH TOOLS *in* AERONAUTICS

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ONE of the important developments of World War II was the application of rockets as military weapons, which led to an active development program on rocket propulsion. The most impressive rocket weapon was, of course, the 12-ton V-2 rocket, the result of scientific and engineering activities dating back to 1934. The place of rocket propulsion in projectiles and missiles is now well established.

Since the war other applications of rockets have been made, and it is with three of these that I wish to treat briefly. All three involve the use of rockets as research tools in aeronautics. The three applications are: To the propulsion of models in free flight for aerodynamic measurements at high speeds; to the propulsion of piloted research aircraft; and to the sounding of the upper atmosphere.

PENETRATING THE SONIC BARRIER

The development of jet propulsion completely revolutionized the art of aircraft design and made possible a great advance in the performance of aircraft, especially as regards speed. In particular, aircraft speeds almost immediately entered the so-called transonic or mixed-flow region in which the air flow begins to change from the subsonic to the supersonic type. For years it had been supposed that aircraft could not penetrate beyond a "sonic barrier," the region where the drag of the aircraft increased disproportionately. Early experience with the severe trim changes and large stick forces encountered as the speed was increased led to the picture of the transonic region as a region to be avoided or hurriedly traversed. The flight of the Bell X-1 to supersonic speeds has modified this concept. In particular, a look at the quantitative information obtained led to the exercise of engineering ingenuity to find methods of dealing with or minimizing the difficulties encountered. As is always the case, knowledge dissipated fear. The pendulum has now swung. Designers are clamoring for specific information on aerodynamic and propulsion characteristics of all possible configurations at transonic speeds so that practical aircraft can be built to fly in and through this region.

The NACA and other research agencies anticipated this need by a few years and undertook to develop techniques for research in this field. Unfortunately, wind tunnels, the most useful research tools at subsonic speeds, have limitations at speeds at and near the speed of sound because the passage chokes, blocking further speed increase when the speed at the narrowest cross section reaches the speed of sound. There is a blind spot whose width is dependent on the size of model and on its shape.

One of the early techniques was to drop heavily weighted models from an aircraft at high altitude. If the weight per unit frontal area is sufficiently great, speeds up to and slightly exceeding the speed of sound can be obtained. By telemetering accelerometer readings and by radar tracking the drag can be measured.

Another of the earliest techniques, the wing-flow method, was developed by R. Gilruth and his co-workers at the NACA Langley Aeronautical Laboratory. Gilruth took note of the increase in local air speed above the curved upper surface of an airplane wing in flight. The local speed may be one and one-half or more times the flight speed so that there is a region near the wing of an airplane flying at 0.7 the speed of sound where the local speed exceeds the speed of sound. While there are speed gradients present, the speed is approximately uniform over a region of sufficient size to include a small scale model. Gilruth mounted small models on a balance built into the upper surface of a fighter airplane which could be dived at high speed. While the models are small and the conditions not ideal, for a time this and the dropped-body technique were the only methods of study in the transonic region. The method yielded information of great value and is still useful.

Shortly after the wing-flow method was in use, the same general principle was applied to wind tunnels by the Lockheed Company in the GALCIT Cooperative Wind Tunnel and by the NACA in the Langley 7 × 10-ft wind tunnel. The local transonic region was created by installing a "bump" on the wall of the wind tunnel, hence the name "bump method."

ROCKET-PROPELLED RESEARCH MODELS

These methods have now been supplemented by another method, the rocket-propelled model, made possible by the general availability of rockets. In 1945 the NACA established a field test station for this purpose at Wallops Island, Va., on the Atlantic Coast south of the Naval Ordnance Test Station at Chincoteague. The information obtained by this method has been found so useful to aircraft designers that the station has continued to grow, and a committee of aircraft designers recommended recently that its activities be increased threefold.

The research models are propelled by standard rocket motors rebuilt to specifications of size and performance suitable for the particular aerodynamic models they propel. Much of the work has been done with standard $3^1/_2$ and 5-in. solid-propellant rockets used by the military services to propel explosive charges. The rockets are modified by changes in the nozzle and igniter to give the desired thrust and operating time and by adding tail pipes as needed. Often two rockets are used in sequence as booster and sustainer.

The simplest type of research model is that used for measurements of drag at zero lift. This model consists of a standard rocket placed inside a light wooden body or fuselage which may or may not carry wings, fins, or wings and tail of the configurations to be studied. The model itself contains no instrumentation. A typical drag model is about 5 in. diam, 56 in. long, and weighs 35 to 45 lb at firing. With a second booster rocket, a speed of about 1.9 times the speed of sound is reached, without it about 1.2 to 1.5 times the speed of sound, depending upon the weight. The distance from the

Address contributed by the Aviation Division and presented at a dinner of the American Rocket Society in conjunction with the Annual Meeting, New York, N. Y., November 28–December 3, 1948, of The American Society of Mechanical Engineers.

ground station to the rocket is recorded by means of a Doppler radar, and from the record the speed and acceleration or deceleration can be determined accurately. The drag is determined from the deceleration of the missile after the rocket has burned out. The effects of wing planform, thickness, and aspect ratio have been determined for many configurations, including sweptback and triangular wings.

A less simple model is used to measure control surface effectiveness. This model carries a small radio transmitter which transmits a continuous signal from an antenna which has marked directional characteristics, this instrumentation occupying the nose. These models are somewhat heavier than the drag models, weighing 100 to 120 lb. The wings are equipped with trailing-edge flaps which are deflected in opposite directions on the two sides, thus causing the model to spin. Because of the directional characteristics of the antenna, the signal received on the ground fluctuates in intensity, the number of fluctuations per second corresponding to the rate of rotation, which is a measure of control effectiveness. In some instances, the spin is observed to slow down and change sign as the speed is increased or decreased through a certain range. Such a result indicates a reversal of control effectiveness in certain speed ranges for that type of control-surface design.

Other missiles carry more complex instrumentation and permit other types of measurement. Telemetering is used to transmit the measurements to the ground. Longitudinal acceleration, lateral acceleration, impact pressure, control-surface position, and hinge moments of control surfaces are some of the quantities which can be measured. Programming devices may be used to oscillate the control surfaces or to displace them suddenly and repeatedly. By such methods, information can be obtained about longitudinal and lateral stability, damping and period of oscillations, effectiveness of controls, pressure distribution, and similar aerodynamic characteristics as a function of speed through the transonic region. The models may represent the configurations of piloted aircraft or missiles intended to be constructed.

Rocket-propelled models may be used for many other special investigations, for example, the study of wing flutter and the study of aerodynamic heating. An important problem under study by this method is that of pilot escape from transonic and supersonic aircraft. The nose section containing the cockpit may be released at high speed, and its motion and acceleration telemetered to the ground. The techniques are constantly being developed to permit the study of many of the new problems of high-speed flight.

ROCKET MOTORS FOR AIRCRAFT

The second application of rockets is to the propulsion of piloted aircraft, specifically to the research airplanes. The concept of building a special research airplane for the sole purpose of making quantitative measurements at very high speeds arose, probably in many minds, in the year 1944. The proposal was vigorously advocated by John Stack and discussed within the NACA staff and the NACA Aerodynamics Committee. Within a year the military services were engaged in receiving proposals, and a co-ordinated program was arranged, involving the study of conventional and sweptback wings of two thicknesses and the use of turbojet and rocket power. The Navy sponsored the Douglas D-558 series, the Air Force the Bell X-1 series. The D-558 early captured the speed record, since exceeded by the F-86, and the X-1 was flown faster than sound. Striking as these performances are, these accomplishments were but incidental to the chief purpose and are not nearly so significant as the quantitative data already obtained and those now being obtained on drag, stability, trim changes, air loads, and the like, at all speeds within the capabilities of the aircraft.

There are many misconceptions about the X-1. It is not a tactically useful airplane; it was designed for 500 lb of instruments, strength to withstand a load of 18 times its weight; it was kept small so that control forces could be kept within the capabilities of the pilot; and it can fly at full power for only a few minutes. Its aerodynamic design was not regarded as optimum for supersonic speeds; it was built to verify results obtained by other methods and to further study the behavior of conventional configurations. Only a rocket could furnish sufficient thrust to drive this configuration at supersonic speeds and then only at very high altitudes where the drag is reduced because of the reduced air density. It seems unlikely that rocket engines will be used as the main power plant of useful piloted aircraft because of the tremendous fuel consumption, although they will probably be used as auxiliary power plants for take-off and combat.

BRIEF DETAILS OF ROCKET ENGINE

The rocket engine is Reaction Motors RMI-6000C4, having a total thrust of 6000 lb with an engine weight of 210 lb. The X-1 carries 8177 lb of fuel (61 per cent of the gross weight of the airplane) which at full power is consumed in 2.5 min (54 lb per sec). The engine uses alcohol and liquid oxygen which are forced through the supply nozzles by the pressure from compressed nitrogen gas.

The engine consists of four separate chambers grouped into a single unit. By this means the pilot may select a thrust of 1500, 3000, 4500, or 6000 lb at will. He may also turn any tube on or off at will and thus has a 4-step control until the fuel is exhausted. The chamber pressure is 230 psi, and the combustion temperature is about 5000 deg R. To cool the chamber the alcohol fuel is mixed with about 25 per cent water and circulated through a cooling jacket around the nozzle before passing to the combustion chamber. Addition of the water is said to have only a slight effect on the thrust.

The first flight of the XS-1 with this rocket engine was made on December 9, 1946, a Mach number of 0.79 being reached at 35,000 ft with half power. Since then the airplane has made many flights in the hands of several pilots.

Other research airplanes will use rocket engines as auxiliary power plants to enable the attainment of still higher speeds. I should like to emphasize again that the interest is not in speed records but in research data throughout the speed range. The engineer is concerned with that region within which large changes in characteristics occur, which is different for different airplanes in the series. The expected phenomena are known to some extent from wind-tunnel data, dropped-body tests, wing-flow tests, and rocket-propelled-model measurements. Research airplanes provide the final check and give confidence to designers to proceed with practically useful aircraft capable of flight in the transonic and supersonic regions.

SOUNDING ROCKETS

A third application of rockets as research tools in aeronautics is to the study of conditions in the upper atmosphere. Interest in the upper atmosphere arises from many sources, for the conditions there have a profound influence on human affairs. Astronomers have been annoyed with the interference of the atmosphere in their observations, for even in the absence of clouds an ozone curtain shuts off a view of the short-wave-length end of the spectrum of stars and sun and so denies them some information on the constitution and physical state of the heavenly bodies. Ordinarily men are thankful for the existence of the curtain because it protects them from the harmful

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carried over into government, then at last there is hope for the future.

Already there are signs that this is taking place. If we look back on the industrial pattern, we find that scientific management did not start usually at the top of the organization. Technicians who believe in scientific management, like the industrial engineers, were given a chance to show what they could do by progressive top managements, and they were the ones who really carried the banner of scientific management forward. With surges ahead alternating with discouraging setbacks, they gradually demonstrated the value of the scientific approach, particularly on manufacturing problems, until its worth began to be recognized, accepted, and adopted by other areas of the business.

So it may be in government. Scientific management is now beginning to get into the more technical levels of government. The Society for the Advancement of Management, for example, has a government-relations division which is encouraging the application of scientific management to government activities. The Army and Navy have finally dropped their 36-year-old restrictions against the use of time study. The same sort of thing is beginning to happen within government circles in other countries.

It is a hopeful development, for from this modest beginning the scientific approach is bound to spread upward through the years and eventually will affect the higher levels. Cold scientific reason will probably never prevail entirely in the management of human affairs, but the scientific approach can recognize the emotional factors which exist within any situation and perhaps can learn to control them within limits.

CHALLENGE TO SCIENTIFIC MANAGEMENT

This then is a challenge for scientific management. Is it too much to expect that if we in industry demonstrate constantly the value of the scientific-management method, the day eventually will come when the managers of countries will follow our example and will eliminate the obstacle of war and provide the incentives which will result in lasting world peace? Here indeed is a cause which deserves the support of every responsible management man who wishes to see his children and his neighbors' children grow up in a better world. Scientific management can be a vital factor in world affairs. Let us all resolve to give it our utmost support whenever and wherever we can.

If we do this with sincerity, then these United States need not be "The last best hope on earth," but rather, a new hope—a new hope for maturity in governmental and international affairs—a new hope for a better future everywhere in the world.

Rockets as Research Tools in Aeronautics

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radiations of the sun. Communication engineers know the interruption to the transmission of speech and code messages when the upper atmosphere is disturbed. The commercial value of uninterrupted communication added to the curiosity of scientists led to intensive study of the upper atmosphere by many indirect means.

Rockets in the course of their military uses have actually propelled vehicles to high altitudes, and the knowledge and experience gained in their development make possible the design of special sounding rockets for the direct study of physical phenomena at high altitudes. A new incentive for such study has also arisen. The air-breathing forms of jet propulsion consume fuel at a much smaller rate than the rocket, since the oxygen then comes from the atmospheric air. Therefore, air-breathing engines should be used wherever possible. Economic travel at supersonic speeds will be possible only at high altitudes. However, the difficulty of keeping the fire burning in an air-breathing jet-propulsion engine increases as the altitude of operation is increased. To study these problems, as well as the lift, drag, and stability of vehicles, we need to know the physical conditions so that they can be reproduced on the ground in laboratory research equipment.

One of the principal uses of the captured V-2 rockets which are being fired by the Army Ordnance Department at White Sands is this type of study. A great many agencies have cooperated in the work. Special sounding rockets have now been developed and the work will proceed at a greater rate. The NACA is engaged in the problem of reproducing the physical conditions of interest for studies of aerodynamic and combustion phenomena. One of its many advisory subcommittees serves as a meeting place for exchange of scientific data on problems of the upper atmosphere.

I will leave to others the prophecy of the future uses of rockets. What I have outlined is what rockets are now doing to advance aeronautics.

Air Transportation

ACCORDING to the Air Transport Association of America, the scheduled airlines of the United States completed the year 1948 with one of the best all-around safety records in the history of commercial aviation.

The domestic scheduled airline record for the year was 1.41 passenger fatalities for each 100,000,000 passenger-miles flown (equal to approximately 4000 trips around the earth at the equator). This compares with 3.2 passenger fatalities for each 100,000,000 passenger-miles flown in 1947.

These figures are based on data furnished by the research department of the Air Transport Association of America.

During 1948 there were four accidents on the domestic airline routes involving 83 passenger fatalities, while in 1947 there were five accidents involving 199 passenger fatalities.

The U. S. flag carriers operating internationally completed the year with a record of one accident on scheduled flights, involving 20 fatalities. This gives the U. S. overseas operators a record of 1.06 fatalities per 100,000,000 passenger miles, as compared with 1.08 for 1947.

Much of the credit for the improving safety records for U. S. airlines, according to an ATA spokesman, can be given to the concentrated program carried on by the airlines and government agencies throughout 1948 for the purpose of improving safety and dependability. This program, which will continue for several years, includes the installation and operation of the Instrument Landing and Ground Control Approach Systems; traffic segregation in congested areas; improved radio communications; high-intensity approach lighting system; a 50 per cent reduction in ground delays; tremendous reduction in maintenance delays; and other navigational and traffic improvements.

The safety record is said to be more remarkable because during 1948 many airlines inaugurated new types of equipment which required the retiming of schedules and revision of many departure and arrival patterns. Additional installation of new navigational equipment in the airplanes and on the ground is contemplated.